The Influence of Long-term Crop Rotations on Vesicular-arbuscular Mycorrhizae Infection of Spring Wheat.

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Vesicular-arbuscular mycorrhizae (VAM) play an important role in the nutrition of many agriculturally important crops. Because of the ubiquitous nature of the mycorrhizal association and the important role that VAM play in crop nutrition and growth, factors affecting this beneficial association need to be identified. Field studies were conducted to monitor the influence of long-term crop rotations on VAM infection of spring wheat. Wheat root samples were collected at regular intervals from Agriculture Canada long-term rotation studies located at Swift Current, Indian Head, Scott and Melfort, Saskatchewan. Root segments were stained, and percent infection was determined by microscopic observation. VAM infection was favoured by continuous wheat rotations at all but one location. The exception existed in the brown soil zone were VAM infection was reduced in the continuous rotation. Likewise, the inclusion of summerfallow in the rotation sequence reduced VAM infection. Phosphorous application generally reduced levels of VAM infection. Factors influencing the VAM association included length of rotation and fertilizer application history.

INTRODUCTION

Most agriculturally important crops coexist with fungal root endophytes forming beneficial symbiotic associations called vesicular-arbuscular mycorrhizae (VAM). The Cruciferae and the Chenopodiaceae are the only families containing a number of crops of agricultural significance that do not form symbiotic associations with VAM fungi (6). Geographically, the association is ubiquitous, occurring in arctic, temperate and tropical regions (17).

Improved crop growth associated with VAM infection is often attributed to enhanced nutrient uptake (1). Following initial infection, extramatrical hyphae extend several centimeters into the surrounding soil, effectively extending the soil volume explored and the absorptive surface area of the root system (14). As a result, the fungal hyphae are able to procure relatively immobile elements such as phosphorus (8, 18) and several micronutrients, including copper and zinc (5,15), from beyond the zone of depletion at the root surface. Other benefits of mycorrhizal infection in some crops may include improved drought resistance (19) and salinity tolerance (11), enhanced nodulation of legume roots by nitrogen fixing rhizobium and increased disease resistance (3).

Kucey (12) surveyed several central and east central Saskatchewan soils and concluded that mycorrhizal fungi are present in sufficient numbers in Saskatchewan soils to be an important factor in crop growth. Furthermore, he observed that virgin soils contained more spores than cultivated soils and concluded that management practices such as summerfallowing and crop rotation might affect mycorrhizal spore numbers. Other studies have indicated that previous cropping history and fertilizer application can influence VAM fungi populations (9); however, this research was conducted in England and may not be applicable to the western Canadian agroclimate. This study was initiated to determine the infectivity of VAM in the Brown, Dark Brown and Black soil zones in Saskatchewan and to study factors which may affect mycorrhizal infection including soil management practices and cropping sequence.

MATERIALS AND METHODS

The effect of crop rotation and long-term fertility regime on VAM infection of spring wheat was investigated during the 1989 field season. Soil and root samples were collected from four long-term rotation research experiments previously established by Agriculture Canada. These long-term rotation studies were located on Agriculture Canada Research

Stations at Indian Head, Swift Current, Melfort and Scott. Characteristics of the study sites are given in Table 1.

Table 1. Characteristics of the Agriculture Canada long-term rotation study sites.

Agriculture Canada Research Station	Soil Classification	Soil Association	Year Rotation Study Initiated
Swift Current	Brown Chernozem	Wood Mountain loam (13)	1967
Indian Head	Thin Black Chernozem	Indian Head clay (4)	1958
Scott	Orthic Dark Brown Chernozem	mixed Elstow and Shallow Elstow loam (4)	1965
Melfort	Orthic Deep Black Chernozem	Melfort silty clay (4)	1959

The long-term fertility regimes and rotations varied considerably from site to site, reflecting the differences in predominate cropping practices in each of the areas. Furthermore, not all of the existing rotation treatments at each of the sites were deemed to be relevant to this study and, as a result, only selected treatments were sampled at each site. All treatments were replicated four times with the exception of the Swift Current rotations where treatments were replicated three times. The rotation treatments sampled at each site are outlined in Table 2.

Table 2. Long term fertility treatments and rotations at Swift Current, Indian Head, Scott and Melfort.

Treatment[a] (rotation)	Swift Current	Indian Head	Scott	Melfort
	Fertilizer treatment (kg ha^{-1})			
cont. ***WH*** (fert.)	3.7 -20.8 N, 17.1 P_2O_5	83 N, 25 P_2O_5	46 N, 25 P_2O_5	58 N, 31 P_2O_5
cont. ***WH*** (unfert.)	NA[b]	0 N, 0 P_2O_5	NA	0 N, 0 P_2O_5
SF - ***WH*** (fert.)	3.7 N, 17.1, P_2O_5	5 N, 25 P_2O_5	11 N, 30 P_2O_5	24 N, 31 P_2O_5
SF - ***WH*** (unfert.)	NA	0 N, 0 P_2O_5	NA	NA
SF - ***WH*** - WH (fert.)	3.7 N, 17.1 P_2O_5	5 N, 24 P_2O_5	6.6 N, 31.6 P_2O_5	41 N, 31 P_2O_5
SF - ***WH*** -WH (unfert.)	0 N, 0 P_2O_5	0 N, 0 P_2O_5	NA	0 N, 0 P_2O_5
SF - WH - ***WH*** (fert.)	3.7-49.4 N, 17.1 P_2O_5	83 N, 25 P_2O_5	40 N, 31 P_2O_5	37 N, 31 P_2O_5
SF - WH - ***WH*** (unfert.)	0 N, 0 P_2O_5	0 N, 0 P_2O_5	NA	0 N, 0 P_2O_5
SF - CN - WH (fert.)	NA	NA	46 N, 25 P_2O_5	NA
SF - CN - ***WH*** -WH (fert.)	NA	NA	NA	57 N, 31 P_2O_5
SF - CN - WH - ***WH*** (fert.)	NA	NA	NA	57 N, 31 P_2O_5

a - SF denotes summer fallow, WH denotes spring wheat, CN denotes canola. The bolded and italicized letters denote the treatment and year of the rotation.
b - denotes "Not Available".

At each site, treatments were sampled at four times during the growing season. At each sampling date, soil and root samples were excavated to a depth of 15 cm, bagged, and transported to the laboratory. Roots were retrieved from the bulk samples by washing the soil with a gentle stream of water. Root samples were then stained (16) and placed in a glass petri dish marked with a one cm grid. Percent infection was determined microscopically by observing the presence or absence of VAM hyphae, arbuscules and vesicles at 100 random intersects.

RESULTS AND DISCUSSION

The effects of long-term crop rotations and fertilizer application on the percent VAM infection of spring wheat roots at Swift Current, Indian Head, Scott and Melfort are reported in Tables 3 - 6.

Table 3. Effects of long-term crop rotations on percent VAM infection of spring wheat roots at Swift Current, 1989.

Treatment (rotation)	Days after Planting (DAP)			
	25	45	65	85
continuous wheat (fert.)	14.3	13.0	16.3	18.0
SF - *WH*(fert.)	6.0	14.7	21.3	25.7
SF - *WH* - WH (fert.)	10.0	11.0	32.3	32.3
SF - WH - *WH* (fert.)	7.7	13.3	22.3	31.7
SF - *WH* - WH (unfert.)	11.0	28.0	48.3	58.3
SF - WH - *WH* (unfert.)	24.0	45.0	55.7	68.0
LSD (p = 0.05)	9.3	13.6	17.8	16.5

Table 4 . Effects of long-term crop rotations on percent VAM infection of spring wheat roots at Indian Head, 1989.

Treatment (rotation)	Days after Planting (DAP)			
	18	40	60	80
continuous wheat (fert.)	34.3	35.8	37.5	59.5
continuous wheat (unfert.)	35.5	57.5	56.0	71.0
SF - *WH* (fert.)	12.5	32.5	25.3	38.3
SF - *WH* (unfert.)	14.0	42.5	51.5	49.3
SF - *WH* - WH (fert.)	24.4	28.0	29.3	51.8
SF - WH - *WH* (fert.)	33.5	32.5	31.5	52.0
SF - *WH* - WH (unfert.)	23.8	32.0	31.8	46.5
SF - WH - *WH* (unfert.)	29.8	39.5	48.5	61.0
LSD (p = 0.05)	12.2	15.7	13.3	13.5

Table 5. Effects of long-term crop rotations on percent VAM infection of spring wheat roots at Scott, 1989.

Treatment (rotation)	Days after Planting (DAP)			
	27	47	67	89
continuous wheat (fert.)	21.0	11.5	21.8	19.8
SF - ***WH*** (fert.)	11.8	5.3	18.0	14.8
SF - ***WH*** - WH (fert.)	13.5	5.8	23.5	21.0
SF - WH - ***WH*** (fert.)	18.8	16.8	37.8	33.8
SF - CN - ***WH*** (fert.)	19.8	9.0	23.5	23.0
LSD (p = 0.05)	7.9	8.4	16.4	13.6

Table 6. Effects of long-term crop rotations on percent VAM infection of spring wheat roots at Melfort, 1989.

Treatment (rotation)	Days after Planting (DAP)			
	27	47	67	88
continuous wheat (fert.)	34.3	17.0	24.5	29.0
continuous wheat (unfert.)	35.8	38.3	57.0	63.8
SF - ***WH*** (fert.)	17.3	15.0	35.5	46.3
SF - ***WH*** - WH (fert.)	11.3	28.3	35.5	38.3
SF - WH - ***WH*** (fert.)	33.5	30.8	26.0	39.8
SF - ***WH*** - WH (unfert.)	31.0	52.5	45.5	52.3
SF - WH - ***WH*** (unfert.)	22.8	33.5	41.0	37.3
SF - CN - ***WH*** (fert.)	14.5	26.5	24.3	41.0
SF - CN - ***WH*** - WH (fert.)	9.5	28.5	20.0	28.0
SF - CN - WH - ***WH*** (fert.)	21.0	20.5	23.8	23.5
LSD (p = 0.05)	15.9	21.4	17.6	17.6

Results indicate that fertilizer application had a pronounced effect on the levels of VAM infection in spring wheat roots at all experimental locations. These results are in keeping with a number of studies which have indicated that both phosphorus (9) and nitrogen (10) may significantly reduce root colonization. For example, at both Indian Head and Melfort, fertilization of continuous wheat generally reduced infection (Fig.1). It is interesting to note that levels of VAM infection at both sites were not affected by fertilizer application at the earliest sampling period and that statistically significant reductions in VAM infection were observed at later sampling periods. This suggests that although early infective stages were relatively unaffected by fertilizer application, subsequent colonization of roots was impeded in the presence of high levels of fertilizer. Moreover, fertilizer application likely increased total root length, and it is possible that root length increased more rapidly than VAM infection and colonization, resulting in an apparent decline in the levels of VAM infection.

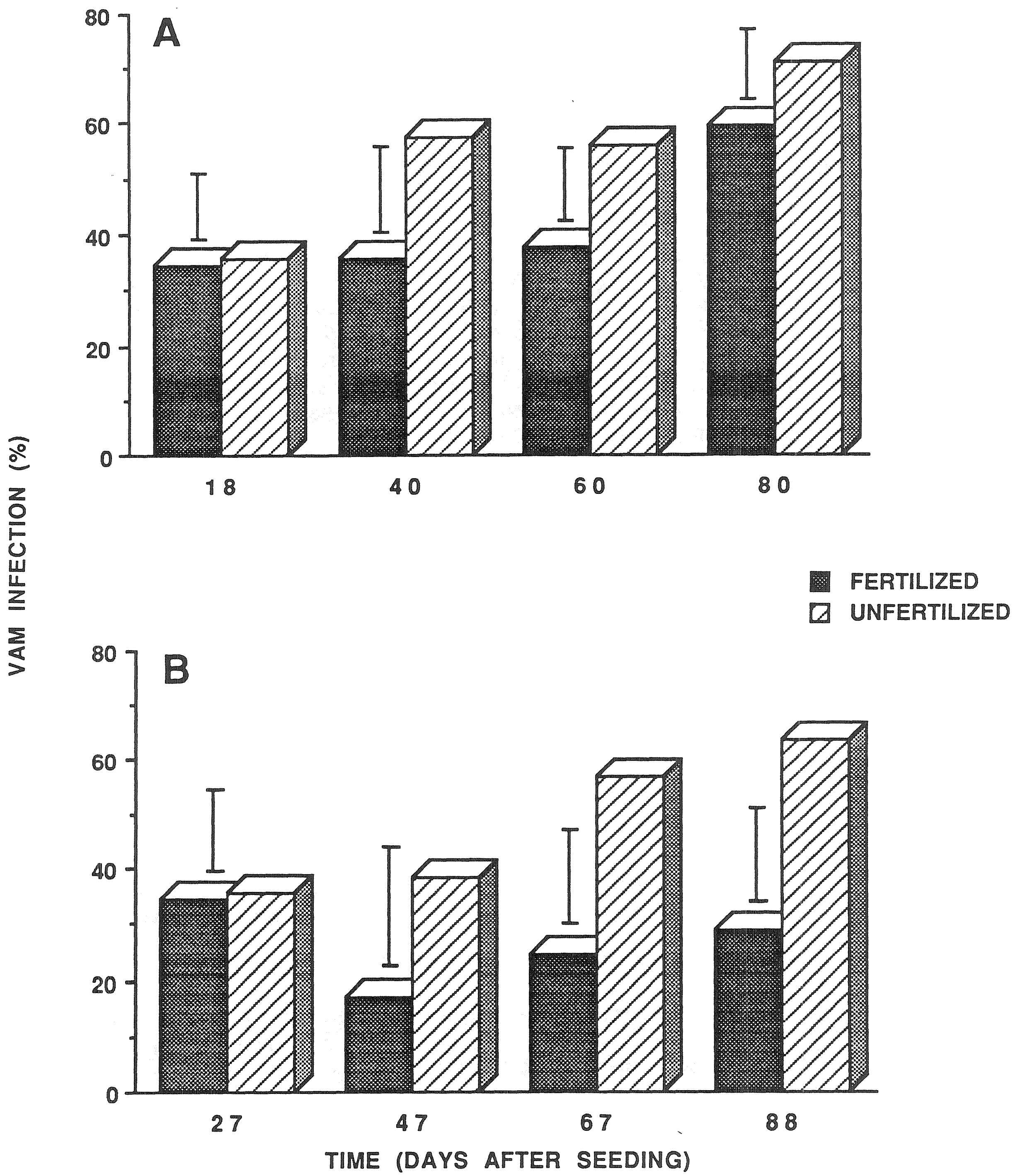

Figure 1. The effect of fertilizer application on percent VAM infection of spring wheat grown in a continuous rotation at Indian Head (A) and Melfort (B).

Similar results were observed at Swift Current in both the second and third year of a three year summerfallow - wheat - wheat rotation (Fig. 2). In the second year of the rotation, VAM infection was unaffected by fertilizer application at the first sampling period (Fig. 3a). Although statistically significant only at the final sampling period, data suggest that VAM infection was reduced at the subsequent sampling periods by fertilizer application. In the third year of the rotation, however, VAM infection was significantly reduced by the application of fertilizer at all sampling dates (Fig. 2b). It is of interest to note that very little fertilizer N was applied at Swift Current to the fertilized treatments (i.e. 3.7 kg N ha-1 was applied to all but one treatment) which suggests that the reductions associated with fertilizer application were primarily associated with application of phosphate fertilizer.

Crop rotation was also observed to significantly affect the level of VAM infection in spring wheat. For example, at Indian Head, levels of VAM infection in the unfertilized continuous wheat rotation were generally higher that the levels of VAM infection in wheat grown on summerfallow (Fig. 3). Thus inclusion of summerfallow in the rotation led to reduced levels of VAM infection in the subsequent crop. It is likely that reduced VAM infection resulted as a consequence of a reduction in the number of infective propagules present in the soil during the summerfallow year. VA mycorrhizae are dependent on the presence of a host crop for growth and spore production. Spores germinating in the absence of a suitable host will eventually exhaust reserves and die out.

Comparison of the levels of infection in the continuous wheat rotation versus levels of VAM infection in the second and third year of the summerfallow - wheat - wheat rotation at Indian Head indicate a similar trend (Fig. 4a). VAM infection was reduced in the second year of the rotation (i.e., wheat grown on summerfallow) as compared to the continuous wheat rotation. Levels of VAM infection did, however, recover somewhat in the third year of the rotation although data suggest that even in the third year of the rotation, levels of VAM infection continued to be reduced by the preceding summerfallow year. These trends were not observed, however, where fertilizer had been applied (Fig. 4b), suggesting that fertilizer application suppressed VAM infection in all treatments to such a degree that differences in VAM infection associated with crop rotation were essentially obliterated.

Inclusion of canola in a rotation would be expected to similarly reduce levels of VAM infection in subsequent crops because canola is a non-host crop. Results from Scott (Table 5) and Melfort (Table 6), however, indicate that inclusion of canola in the rotation had little or no effect on the level of VAM infection in subsequent crops. It is important to note that at both Scott and Melfort, these rotations received relatively high levels of both nitrogen and phosphorus and thus, it is probable that the effect of the high fertilizer rates obliterated any rotation effects. Indeed, VAM infection on these fertilized rotations tended to be very low, regardless of the rotation treatment (i.e., 10 - 35 % VAM infection).

Results of this investigation indicate that VAM infection is influenced both by fertilizer application and crop rotation. It is not known, however, if the effects of fertilizer application and crop rotation are the result of a direct effect of these factors on VA mycorrhizae, or as a consequence of an indirect effect . For example, fertilizer application and crop rotation may influence crop development and (or) the population of soil organisms in general, which may in turn have a subsequent indirect effect on the infectivity of VA mycorrhizae.

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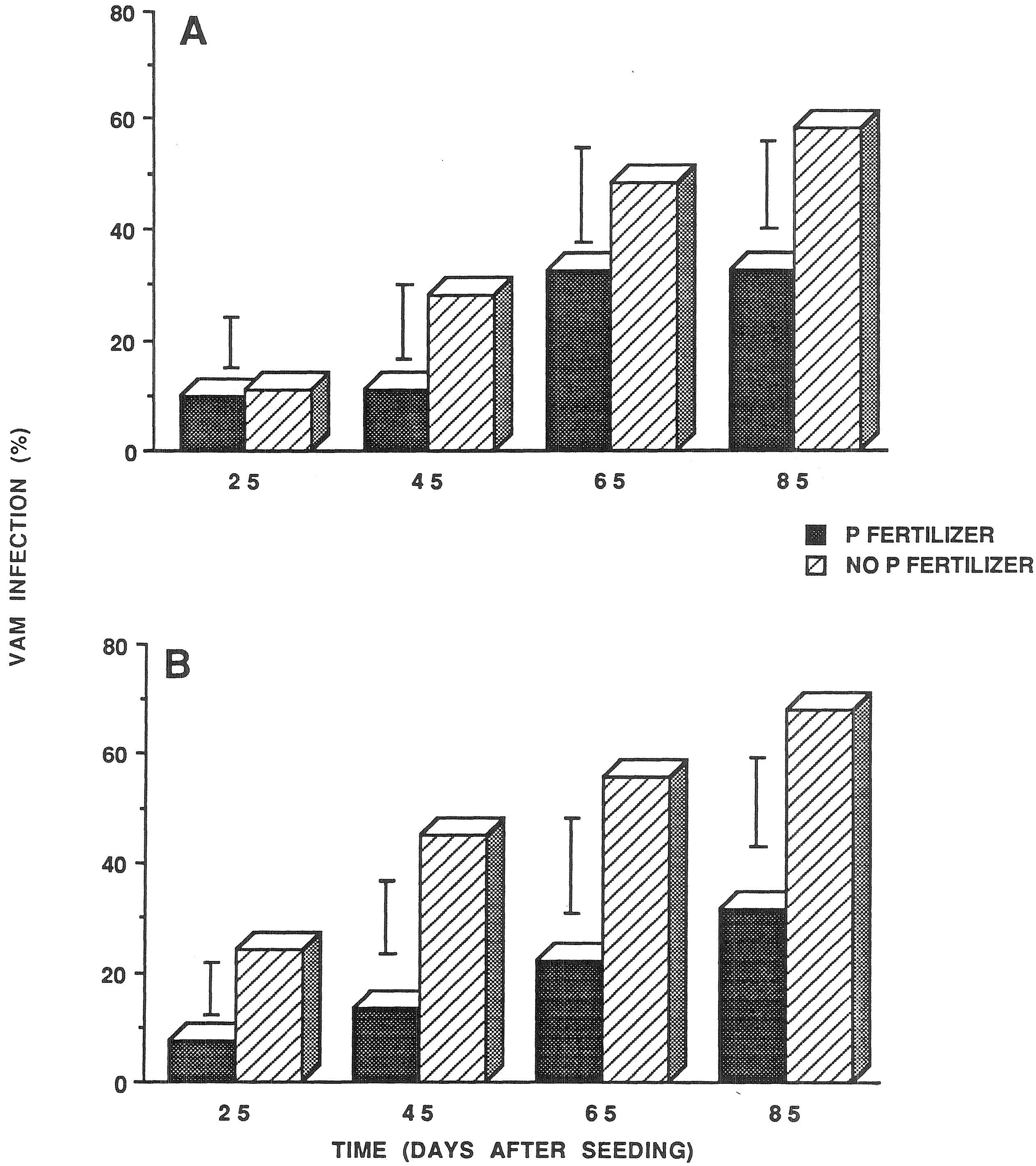

Figure 2. The effect of fertilizer application on percent VAM infection of spring wheat in the second (A) and third (B) year of a three year summerfallow - wheat - wheat rotation at Swift Current.

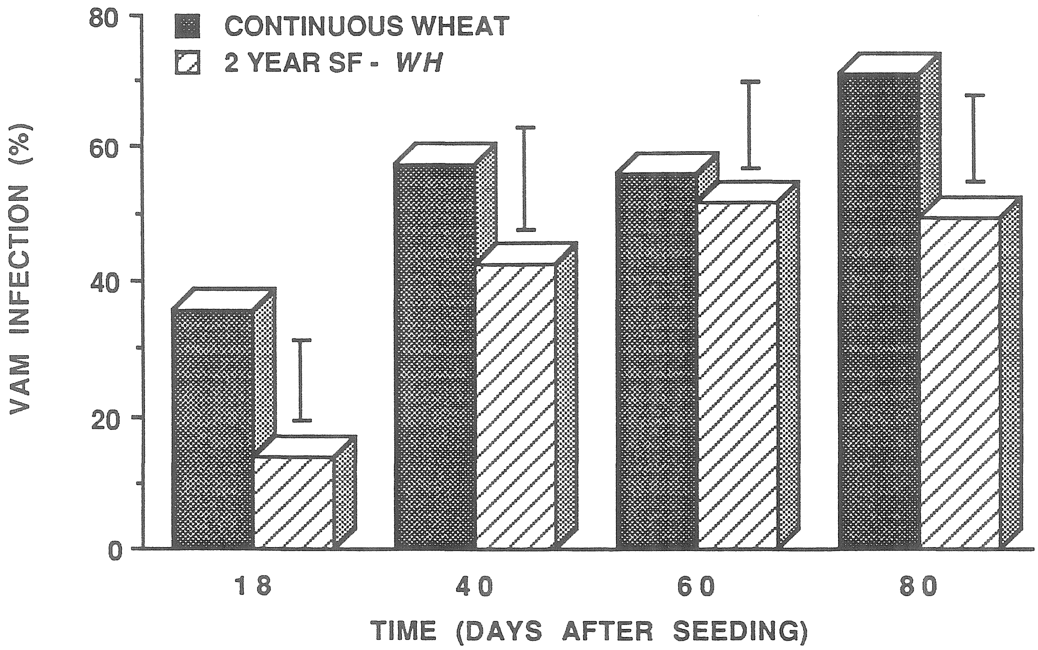

Figure 3. The effect of summerfallow on percent VAM infection of unfertilized spring wheat grown in a two year summerfallow - wheat rotation at Indian Head.

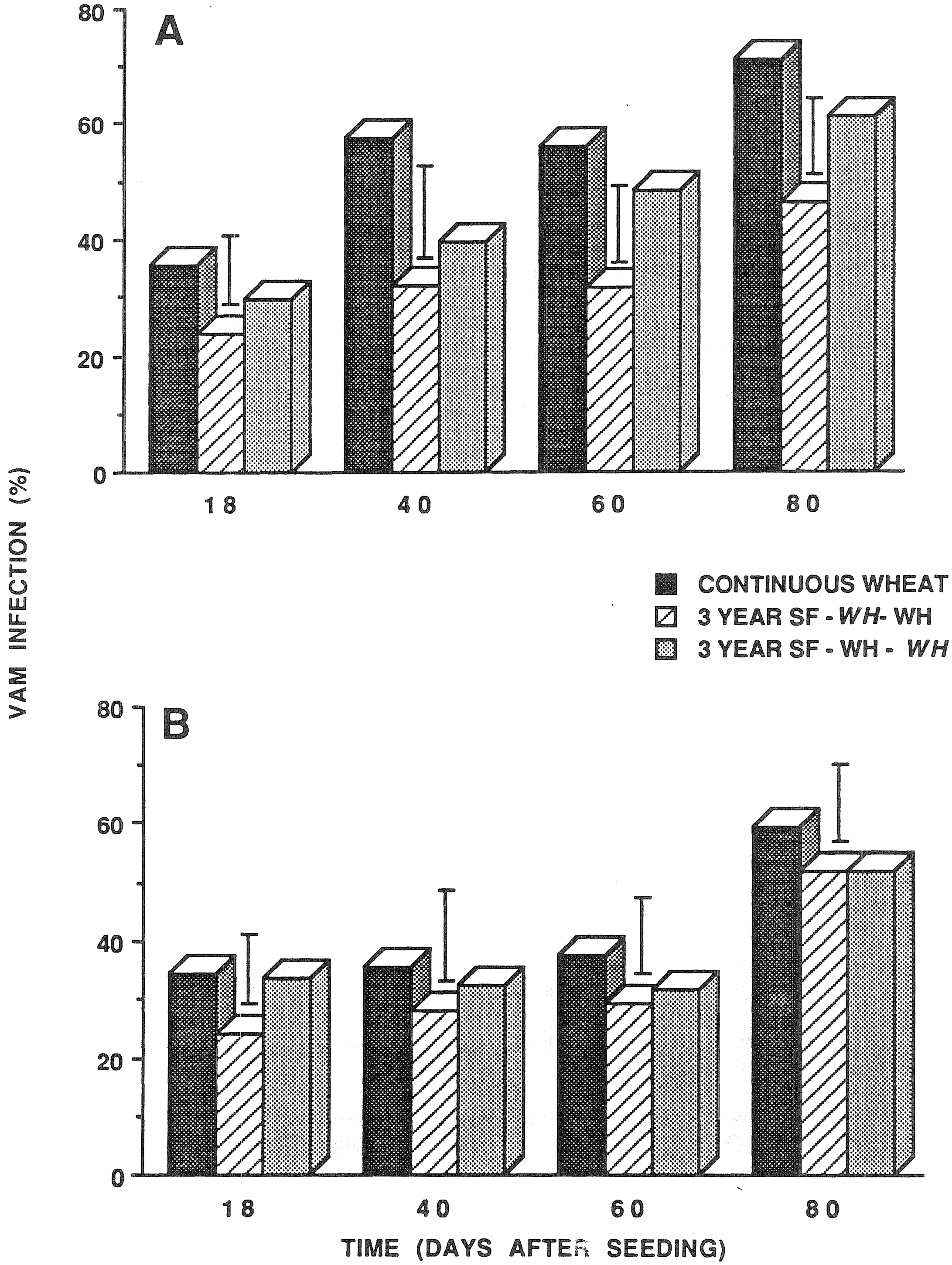

Figure 4. The effect of summerfallow on VAM imfection of spring wheat grown in an unfertilized (A) and fertilized (B) three year summerfallow - wheat - wheat rotation at Indian Head.

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